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Research Article

Analysis of Factors Affecting the Severity of Injuries in Electric Two-Wheeled Vehicle Crashes with or without Violation: A Random Parametric Logit Model considering Heterogeneity of Means and Variances

Fulu Wei,[1] **Yuxin Han**,[1] **Yanyong Guo**,[2] **and Yongqing Guo**[1]

[1]*School of Transportation and Vehicle Engineering, Shandong University of Technology, Zibo 255000, Shandong, China*
[2]*School of Transportation, Jiangsu Key Laboratory of Urban ITS, Jiangsu Province Collaborative Innovation Center of Modern Urban Traffic Technologies, Southeast University, Nanjing, Jiangsu, China*

Correspondence should be addressed to Yanyong Guo; guoyanyong@seu.edu.cn

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Electric two-wheeled vehicle is one of the main commuting tools in China, but they are also more likely to have violations of the road group. In order to study the effect of the presence of violation on the severity of road traffic crashes among electric two-wheeler riders, in this study, the effects of rider characteristics, road characteristics, collision characteristics, and environmental characteristics on the severity of injuries of electric two-wheeled vehicle riders were considered separately analyzed based on the data of 6403 two-wheeled electric vehicle traffic crashes in a region of Shandong Province from 2015 to 2021, and a random parametric logit model considering the heterogeneity of the mean and the variance (RP-HMV logit) was established based on the presence or absence of violation behaviors of riders, respectively, in order to explore unobserved heterogeneity. In order to test the validity of the model for modeling the injury severity of pedestrians riding electric two-wheelers, multinomial logit (MN-logit model), and random parameter logit model (RP-logit) were estimated, and the results showed that the RP-HMV logit model was significantly superior in terms of goodness of fit. The study showed that some of the factors differed somewhat between the two scenarios, such as gender, while the factors that were significant in both scenarios were >60, broken pavement, street lights at night, no street lights at night, mixed motorized and nonmotorized lanes, sidewalks, other angles, no control, severe weather, and visibility <200 m, where the severe weather and visibility <200 m were random parameters obeying normal distributions, there is a significant difference between having street lights and no control at night in both scenarios, and the difference is significant. The results of the study can provide a reference for the development of targeted countermeasures to improve the traffic safety of electric two-wheeled vehicles in China.

1. Introduction

In recent years, electric two-wheeled vehicles have become one of the main means of transportation in China's road traffic due to their high speed and flexibility. According to statistics, the sales of electric two-wheeled vehicles in China will reach 41 million in 2021, with a social population of about 330 million, ranking first in the world [1]. With the increasing number of electric vehicles, road traffic crashes involving electric vehicles have occurred frequently. From 2013 to 2017, about 56200 people were injured and 8431 people were killed in electric two-wheeled vehicle crashes in China. The safety of electric two-wheeled vehicles cannot be ignored [2]. Some research results show that with the substantial increase in the use of electric bicycles, the number of inpatient casualties related to electric bikes has increased sharply [3]. Accident investigations of electric two-wheeled vehicles have revealed frequent violations by riders of electric two-wheeled vehicles, considering that rider behavior is likely to impact accident severity. Still, more studies need to address the impact of rider violations on accident injury severity. Therefore, for the high casualty rate of electric two-wheeled vehicles, it is necessary to deeply analyze the influence factors of the severity of injuries in electric vehicle accidents in terms of the existence of illegal behaviors of electric two-wheeled vehicle riders, which is of great significance to reduce the crash rate of two-wheelers vehicle.

2. Literature Review

At present, the analysis of the severity of electric two-wheeled vehicle crashes focuses on the personal factors and driving behaviors of the electric two-wheeled vehicle riders. Chang studied the severity of the crash and found that the age of riders, intersection control mode, driving speed, and other factors were significantly related to the severity of the crash and put forward improvement strategies from the perspective of 3E (engineering, education, and law enforcement) [4]. Wang researched express delivery electric bicycle riders and found that if riders were familiar with traffic rules, it would play a positive role in increasing helmet-wearing and reducing collisions [5]. Factors such as vehicles and roads have also appeared in the study of the impact on riding safety many times. The research on the head injury of the driver in the electric bicycle-car collision crash found that the impact angle and body size had a significant impact on the severity of the rider's injury [6]. According to the research on the collision location and driving direction of the electric bicycle and the vehicle, the faster the speed is, the higher the risk of death of the rider is, and the age is significantly related to serious and fatal injuries [7]. Yang conducted a reduced-dimension analysis of nine factors, including the speed of the collision object, the running direction of the collision object, the age of the two-wheel electric vehicle driver, the speed of the two-wheel electric vehicle, the running direction of the two-wheel electric vehicle, the obstacle of sight, the driver's illegal behavior, the intersection traffic light, and the collision object [8]. Guo et al.'s research found that age, gender, electric bicycle behavior, license plate, bicycle type, location, and speed limit are significantly related to the severity of the crash [9]. The user experience and risk perception of electric bicycles are added to the analysis of the factors that affect the riding of electric bicycles. It is found that the research has reduced the risk of crashes for riders with higher satisfaction and speed<25 km/h [10].

In addition to the classification and analysis of collision data factors, the model method is also an important factor in studying the impact of crash severity. At present, the models used in the study include the binary logic model. Wang et al. applied the ordered logic model to test the influencing factors of injuries of Guilin electric bicycle drivers in motor vehicle collisions [11]. Guo et al. used the random parameter polynomial logit model (RP-MNL) to analyze 310 electric bicycle collisions in Ningbo, China, and record the severity of electric bicycle collisions [9]. Rifaat et al. used the ordered probability model to analyze the different degrees of injury risk in the collision of different types of vehicles and express motorcycles, identify the main factors of the severity of motorcycle collision crashes, and analyze the relationship between the impact factors of motorcycle collision crashes and the severity of injuries [12]. Part of the study combined with the logistic regression model to analyze the impact of road environment and crash morphology characteristics on the severity of the crash. In order to determine the interaction between factors in the crash, Hu established the interaction effect model analysis and determined that the interaction between multiple factors would increase the risk of electric two-wheel vehicle crashes [13]. Wang established the intermediary logic order model to study the intermediary variables in the crash, further revealing the factors affecting crash safety [5].

In the current research, there is less research on the violation behavior of electric two-wheeled vehicles, and more research is to analyze it as an influencing factor. However, due to the fast and flexible characteristics of electric bicycles and the imperfect management policies for electric bicycles at present, many electric bicycle riders cannot ride in strict accordance with the rules and often have violations such as retrograde and road occupation, which not only endanger their own safety but also have a huge impact on the safety of other road users. According to the current research and statistics on electric bicycles, there are few studies on the impact of the violations of the two-wheel electric bicycle riders on the severity of crash injuries.

In this paper, a random parameter model was used to study the impact of various factors on the severity of the electric two-wheeled vehicle crashes in the two scenarios of whether there are violations when the rider crash occurs and to explore the nonobserved heterogeneity in the crash data. The marginal effect was used to quantitatively analyze the difference in the factors affecting the severity of injury of the electric two-wheeled bicycle riders in the two scenarios. The research in this study can provide a theoretical basis for the relevant departments in traffic management, crash prevention, and governance of illegal behavior of electric two-wheeled vehicles.

3. Data Preparation

3.1. Describe of Dataset. The data come from the crash data of electric two-wheeled vehicles in a certain area of Shandong Province from 2015 to 2021. The data includes 6512 electric two-wheeled vehicle crashes. After cleaning the dataset and deleting the missing and error information records, the final dataset contains 6403 crashes as the research object, including 3915 nonviolation crashes of riders and 2488 violation crashes of riders. Based on this, it can be found that the frequent violations of electric two-wheeled vehicles have a significant impact on road safety [14].

The dependent variable setting in this study was selected as the target variable of the injury severity of electric two-wheeled vehicle riders in traffic accidents. According to the accident data, the degree of injury of cyclists was categorized into four categories, namely, no injury (NI) (14.2%), minor injury (MI) (62.7%), serious injury (7.8%), and fatal injury (15.3%). Among them, if the driver dies within seven days of the accident, the accident is defined as a fatal accident. In view of the small proportion of fatal crashes, if they are directly included in the statistical model, the shortage of samples will inevitably have a negative impact on parameter calibration. Serious injury and fatal are regarded as the adjacent injury severity classification. Combining them into one category and recording them as severely/fatal injury (FS) crashes can solve the problem of poor model fitting performance caused by insufficient samples. This combination of adjacent categories will not have a significant impact on the regression results and has been widely recognized and applied in practice [15].

Sixteen variables were selected as influencing factors to be analyzed in the study. They can be categorized into four groups according to their characteristics, including rider characteristics, road characteristics, collision characteristics, and environmental characteristics. In order to compare and analyze the data results, the study categorized the data according to whether the electric two-wheeled vehicle riders in the collision had violation behaviors (such as driving against traffic, running red lights, and occupying the road). The weather factors, rainfall, snowfall, freezing, high wind (blowing sand), and other weather factors that impact road conditions need to be combined and processed due to the small sample size. These are collectively referred to as severe weather. Descriptive statistics of these variables are shown in Table 1.

The reference variables in Table 1 are selected based on the characteristics of the distribution of collision accident data, as well as the relevant literature. It should be noted that in the collision angle variable, the collision object of electric two-wheeled vehicles includes motor vehicles and non-motorized vehicles.

3.2. Pearson Correlation Coefficient Test. In discrete statistical modeling, a high degree of correlation between the variables can easily lead to bias in model fitting, affecting the accuracy of model estimation. The Pearson correlation test can be used to determine the optimal regression variables. Suppose the absolute value of the Pearson correlation coefficient is less than 0.3. In that case, it is considered that there is no obvious correlation between the two types of variables. Suppose the absolute value is more significant than 0.3. In that case, it is assumed that there is an apparent correlation between the two types of variables, and only one type of variable can be selected for inclusion in the statistical model.

A total of 16 categories of variables were selected for the study, and the data were imported into the Pearson correlation coefficient test. The test results are shown in Figure 1 below.

As can be seen from Figure 1 above, the variable pavement condition has a correlation coefficient of 0.64 with the weather and a correlation coefficient of 0.34 with the pavement material. The absolute values of the correlation coefficients are all greater than 0.3. In order to ensure the accuracy of the results of the subsequent model estimation, the variable pavement condition is deleted from the model estimation.

3.3. Multicollinearity Detection. Multicollinearity refers to the linear correlation between independent variables. That is, an independent variable can be a linear combination of one or more other independent variables. If there is multicollinearity, the matrix is irreversible when calculating the partial regression coefficient of the independent variable. Its performance mainly includes: the variance analysis result of the whole model is inconsistent with the test result of the regression coefficient of each independent variable, the test result of the independent variable with statistical significance of professional judgment is meaningless, and the coefficient or symbol of the independent variable is seriously inconsistent with the actual situation.

In order to define the existence of multicollinearity in the research variables of this paper, the variance inflation factor (VIF) is used to test the multicollinearity between the variables, and the calculation process can be seen in the following equation:

$$\mathrm{VIF} = \frac{1}{1 - R_i^2}, \tag{1}$$

where R_i is the negative correlation coefficient of the independent variables for regression analysis of the remaining independent variables. The larger the variance inflation factor (VIF), the greater the likelihood of covariance between the independent variables. Generally, if the variance inflation factor exceeds 10, the regression model has serious multicollinearity.

A total of 16 influencing factors were selected in the study, including multiple multi classification variables. After all the variables were converted into 0-1 variables, a total of 29 0-1 variables were included. The multicollinearity test results are shown in Table 2 below.

In the table, the maximum VIF value of the crash site in the sidewalk variable is 6.79, but it is less than the threshold value of 10, so it can be determined that there is no multicollinearity between the respective variables.

4. Model Building

4.1. Random Parametric Logit Model considering Heterogeneity of Mean and Variance. In this study, the injury severity of electric two-wheeled vehicle riders was set as the dependent variable, and its utility function, which takes into account the heterogeneity of mean and variance, was established as shown in the following equation [16]:

$$Y_{ij} = \beta_i X_{\mathrm{ij}} + \varepsilon_{\mathrm{ij}}, \tag{2}$$

where Y_{ij} is the utility function of the j electric two-wheeled vehicle accident when the injury severity of the rider is i; X_{ij} is the vector of explanatory variables when the injury severity of the rider in the two-wheeled vehicle accident j is i; β_i is the vector of each estimated parameter; and $\varepsilon_{\mathrm{ij}}$ is the error term.

Table 1: Descriptive statistics.

Variable type	Variable description	Variable symbols	No violations			Existence of violations		
			NI* (%)	MI (%)	FS (%)	NI* (%)	MI (%)	FS (%)
Sex	Female*	—	10.82	41.40	18.37	14.97	36.39	11.60
	Male	X_1	1.73	21.11	6.57	5.43	27.32	4.30
Age	<18*	—	0.78	3.93	0.62	3.09	6.74	0.37
	18–32	X_2	1.99	6.18	1.47	4.21	8.04	0.75
	32–46	X_3	3.18	11.25	3.57	4.49	10.48	1.87
	46–60	X_4	4.79	21.79	8.31	5.89	19.27	6.27
	>60	X_5	1.81	19.35	10.97	2.71	19.18	6.64
Pavement condition	Pavement good*	—	11.69	61.94	24.53	17.31	62.39	15.43
	Pavement damage	X_6	0.85	0.57	0.41	3.09	1.31	0.47
Road surface condition	dry*	—	11.82	57.75	23.08	19.36	58.84	14.41
	damp	X_7	0.72	4.76	1.86	1.03	4.86	1.50
Lighting conditions	Day*	—	7.87	42.74	16.51	14.87	44.90	10.48
	Dusk/dawn	X_8	1.11	3.67	2.10	0.75	2.71	1.03
	Street lights at night	X_9	2.25	10.17	3.73	3.37	10.57	2.90
	No street lamp at night	X_{10}	1.32	5.92	2.61	1.59	5.52	1.50
The road alignment	Straight*	—	10.66	55.19	20.67	19.08	57.81	14.59
	Tortuous	X_{11}	1.89	7.32	4.27	1.31	5.89	1.31
Road type	General urban Road*	—	5.41	23.00	6.24	10.38	29.75	5.61
	Class I-IV highway	X_{12}	3.67	23.26	12.06	5.89	21.23	7.20
	Substandard highway	X_{13}	3.47	16.25	6.65	4.12	12.72	3.09
Crash site	Motorway*	—	8.10	43.91	18.03	11.23	38.63	12.35
	Nonmotorized lane	X_{14}	2.41	8.75	3.00	5.89	16.18	1.50
	Mixed lane	X_{15}	1.37	7.19	2.41	2.62	6.08	0.84
	Sidewalk	X_{16}	0.67	2.66	1.50	0.65	2.81	1.22
Pavement material	Asphalt*	—	11.88	59.30	23.10	20.11	61.37	15.25
	Nonbituminous	X_{17}	0.67	3.21	1.84	0.28	2.34	0.65
Impact angle	Side impact*	—	7.74	49.86	19.38	13.10	47.15	11.60
	Frontal collision	X_{18}	4.06	13.38	1.40	1.78	6.55	1.31
	Rear impact	X_{19}	0.96	5.43	2.48	0.94	5.43	0.94
	Other angles	X_{20}	3.18	3.16	1.68	4.58	4.58	2.06
Traffic control mode	Signal control*	—	2.87	12.86	4.68	5.05	14.78	1.87
	Uncontrolled	X_{21}	3.54	23.75	11.88	5.14	23.57	37.51
	Marking control	X_{22}	6.13	25.90	9.16	10.20	25.35	4.58
Weekly parameters	Working days*	—	9.34	45.30	17.00	14.59	47.24	11.60
	Rest day	X_{23}	3.21	17.21	7.94	5.80	16.46	4.30
Season	Spring*	—	4.09	18.47	7.71	7.02	19.08	5.14
	Summer	X_{24}	2.85	15.19	4.86	6.64	19.08	3.18
	Autumn	X_{25}	3.29	17.59	7.30	3.74	15.25	5.33
	Winter	X_{26}	2.33	11.25	5.07	2.99	10.29	2.25
Weather	Sunny*	—	11.38	20.57	22.17	19.08	55.75	13.66
	Severe weather	X_{27}	1.16	4.14	2.77	1.31	7.95	2.25
Visibility	>200 m*	—	7.61	37.80	14.70	13.47	39.10	9.07
	<200 m	X_{28}	4.94	24.71	10.25	6.92	24.60	6.83
Terrain	Flat*	—	10.04	52.99	19.97	18.33	56.22	13.10
	Nonflat	X_{29}	2.51	9.52	4.97	2.06	7.48	2.81

Note. "*"is a reference variable.

At this time, each regression coefficient β_i is a fixed value, however, in the electric two-wheeled vehicle crashes, the influence of each factor on the severity of the rider's injuries may vary with individual variability, in order to explain the problem of unobserved heterogeneity among the data, β_i is set as a random vector, and in which a mean heterogeneity vector and a variance heterogeneity vector is introduced, i.e., see the following equation:

$$\beta_i = \beta_{ij} + \delta_{ij}M_{ij} + \sigma_{ij}e^{\omega_{ij}D_{ij}}v_{ij}, \tag{3}$$

where β_{ij} is the mean value of β_i; M_{ij} is the mean heterogeneity vector associated with the independent variables; δ_{ij} is the parameter vector to be estimated for M_{ij}; M_{ij} is the variance heterogeneity vector associated with the independent variables; ω_{ij} is the parameter vector to be estimated for D_{ij}; and v_{ij} is the random term with mean 0,

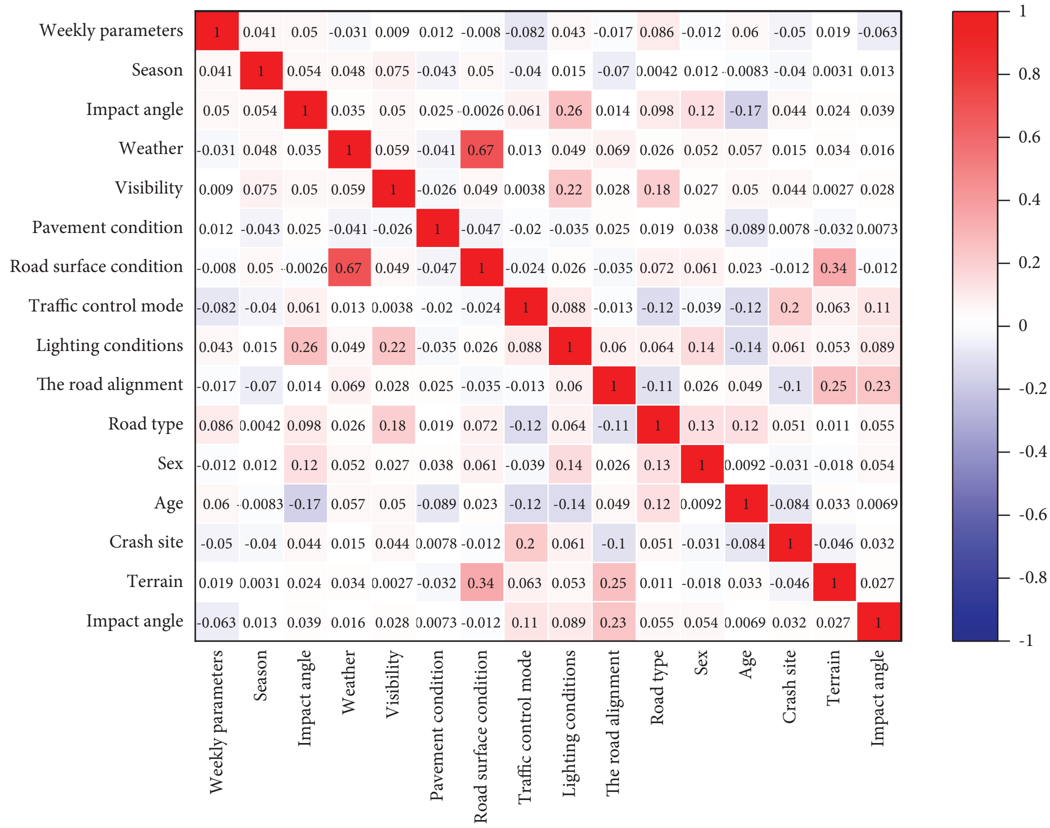


Figure 1: Schematic diagram of Pearson's correlation coefficient.

standard deviation 1. The formula for calculating the model probability is shown in the following equation:

$$P_{ij} = \int \frac{e^{\beta_i X_{ij}}}{\sum e^{\beta_i X_{ij}}} f(\beta_i \mid \varphi) d\beta_i, \quad (4)$$

where P_{ij} is the probability that the severity of the accidental injury of the elderly driver in accident j is i; $f(\beta|\varphi)$ is the β_{ij} probability density function; and φ is the parameter describing the corresponding distribution (mean and variance) vectors.

4.2. Marginal Effect. The parameter estimation results of the random parameter logit model can reflect the influence trend of each variable on the crash severity, but cannot quantitatively explain the influence of each variable on the crash severity. This paper quantitatively describes and analyzes the influence of different significant factors on the severity of injury of electric two-wheeled vehicle riders by using marginal effect. See the following equation:

$$\overline{E}_{X_{ij}}^{P_{ij}} = \frac{1}{N}\sum_{n=1}^{N} \frac{P_{ij}(X_{ij}) - P_{ij}(X_{ij}=0)}{P_{ij}(X_{ij}=0)}, \quad (5)$$

where $\overline{E}_{X_{ij}}^{P_{ij}}$ is the average marginal coefficient of the j factor to the rider's injury severity i; and $P_{ij(X_{ij})}$ is the probability of the j electric two-wheeled vehicle crash when the rider's injury severity is i.

4.3. Model Evaluation. In terms of t goodness-of-fit measure, Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), and McFadden Pseudo R^2 were chosen for this study and the results were calculated as shown in the following equations:

$$\text{AIC} = 2K - 2\ln(L), \quad (6)$$

$$\text{BIC} = K\ln(n) - 2\ln(L), \quad (7)$$

$$\text{McFadden Pseudo}R^2 = 1 - \frac{\ln(L)}{\ln(L_o)}, \quad (8)$$

where K is the number of model parameters; L is the logarithmic likelihood value when the model converges. The smaller the *AIC* and *BIC* value, the better the goodness of fit; *McFadden Pseudo* R^2 has a good goodness of fit between 0.2 and 0.4, and the larger the value, the better the goodness of fit.

5. Model Results and Discussion

5.1. Transferability Test. In order to determine the need for independent modeling of the presence or absence of violations, this paper examines accident data according to transferability theory. A log-likelihood ratio test was first performed between the overall model and the presence or absence of violations model.

Table 2: Multicollinearity diagnosis.

Serial number	Variable	VIF
1	X_1	1.05
2	X_2	1.85
3	X_3	1.44
4	X_4	1.23
5	X_5	1.31
6	X_6	1.02
7	X_7	1.62
8	X_8	6.41
9	X_9	3.97
10	X_{10}	5.26
11	X_{11}	1.43
12	X_{12}	1.23
13	X_{13}	1.29
14	X_{14}	4.45
15	X_{15}	5.12
16	X_{16}	6.79
17	X_{17}	1.17
18	X_{18}	6.13
19	X_{19}	4.67
20	X_{20}	5.00
21	X_{21}	1.80
22	X_{22}	1.71
23	X_{23}	1.01
24	X_{24}	2.39
25	X_{25}	2.11
26	X_{26}	2.63
27	X_{27}	1.62
28	X_{28}	1.36
29	X_{29}	1.66

For portability testing in different scenarios, the first set of likelihood ratio tests is used to compare models between two scenarios and test whether the parameter estimates between these scenarios are stable, which can be defined in the following equation [17]:

$$\chi^2_{t_1} = -2\left[\mathrm{LL}\left(\beta_{y_1 y_2}\right) - \mathrm{LL}\left(\beta_{y_1}\right)\right], \tag{9}$$

where $\mathrm{LL}(\beta_{\mathrm{all}})$ denotes the log-likelihood of convergence of the model containing aggregated data on crashes with and without violations, and $\mathrm{LL}(\beta_v)$ and $\mathrm{LL}(\beta_{\mathrm{nv}})$ denote the log-likelihood of convergence of the models for crashes with and without violations for riders, respectively. The degrees of freedom are equal to the sum of the statistically significant parameters for the presence and absence of violation behavior of the cyclist minus the number of statistically significant parameters in the whole model.

$$x^2_{t_2} = -2\left[\mathrm{LL}\left(\beta_{\mathrm{all}}\right) - \mathrm{LL}\left(\beta_v\right) - \mathrm{LL}\left(\beta_{\mathrm{nv}}\right)\right]. \tag{10}$$

Using the convergence parameters of the no violation behavior model as a starting value and applying them to the presence of violation data gave 21 degrees of freedom, giving $\chi^2 = 104.274$, indicating that the original hypothesis that the two time periods are the same can be rejected at a 99.99% confidence level. Similarly, using the convergence parameter of the model for the presence of violations as a starting value and applying it to the data for the absence of violations gives $\chi^2 = 112.042$ for 27 degrees of freedom, which also demonstrates that the original hypothesis that the two time periods are the same can be rejected at a 99.99% confidence level as shown in Table 3.

5.2. Model Fit Goodness-of-Fit Test. The model was evaluated for goodness of fit and the results are shown in Table 4 below.

From the comparative analysis of the data in Table 4, it is found that the AIC and BIC values of the RP-HMV logit model are smaller than those of MN-Logit and RP-logit in both scenarios, and the McFadden Pseudo R^2 value is the largest, which can be concluded that the fitting effect of the RP-HMV logit data are better, and thus the RP-HMV logit model has a better fitting goodness for the model analyzing the severity of the accidental injuries caused by the presence of the riders with or without violation of the law.

5.3. Model Results and Discussion. In this study, NLOGIT 6.0 was used to construct a random parametric logit model considering mean and variance heterogeneity for parameter estimation of crash data for the two scenarios of no violation and presence of violation, respectively. In order to accurately capture the variables that exhibit random behavior, this study assumes that all variables are random parameters in the regression of the model. Variables that exhibit randomness were identified through the output of the model. In the subsequent model estimation, random parameters were set based on to the output results to better illustrate the existence of unobserved heterogeneity in the data. The model estimation results for the two scenarios are shown in Table 5.

The estimation results by the RP-HMV logit model are shown in Table 5. The results indicate that the variables of male riders, age of riders >60 years old and broken pavement significantly affect the severity of riders' injuries, which may be either positive or negative. To better quantify the effects of the variables on the severity of riders' injuries, we calculated and summarized the average marginal effects, shown in Table 6. Detailed results, categorized by variable, are discussed below.

5.3.1. Random Parameter Analysis. In this paper, to determine the random parameters, all the parameters were preset as random parameters. Also, the parameters were estimated. The model regression results show that in the random parameter logit model, considering the heterogeneity of mean and variance, only two parameters exhibit randomness. These two parameters are severe weather and low visibility (<200 meters). Both of them follow normal distribution.

For severe weather without violation, the mean is 0.8044 and standard deviation is 1.2123. In terms of normal distribution probability density, Figure 2(a) shows that 74.54% of motorized two-wheeler riders have an increased likelihood of minor injuries if they are involved in a collision in severe weather. If the collision occurs in bad weather, it increases the mean value of age coefficient (>60) and increases the probability of minor injuries. This random

Table 3: Great likelihood ratio test for different scenarios.

y_1	y_2 No violations	Existence of violations
No violation	—	112.042 (27) (>99.99%)
Existence of violation	104.274 (21) (>99.99%)	—

Table 4: Evaluation of model goodness of fit.

Evaluation parameter	No violation			Existence of violation		
	MN-logit	RP-logit	RP-HMV logit	MN-logit	RP-logit	RP-HMV logit
AIC	6464.761	6231.255	6023.547	1749.667	1607.823	1532.815
BIC	6840.344	6358.794	6119.755	2048.136	1823.611	1673.227
McFadden Pseudo R^2	0.217	0.264	0.297	0.231	0.295	0.312

Table 5: Estimating the severity of injuries in electric two wheeled vehicle accidents using a random parameter logit model considering the heterogeneity of mean and variance.

Variable	No violation				Existence of violation			
	MI		SF		MI		SF	
	Mean	S.D	Mean	S.D	Mean	S.D	Mean	S.D
Rider factor								
Male	—	—	—	—	−1.188	0.240	−0.958	0.873
18–32	−0.236	0.154	—	—	—	—	—	—
46–60	—	—	—	—	—	—	0.796	0.655
>60	0.151	0.178	0.347	0.212	0.786	0.975	2.017	1.316
Road factor								
Pavement damage	−2.241	0.231	—	—	—	—	0.148	0.247
Dusk/dawn	—	—	—	—	−0.493	0.347	—	—
Street lights at night	−1.145	0.175	—	—	0.258	0.455	—	—
No street lamp at night	0.767	0.159	0.838	0.233	0.426	0.725	—	—
Nonmotorized lane	—	—	—	—	−0.288	0.105	−0.554	0.143
Mixed lane	1.323	0.135	1.171	0.197	0.723	0.535	0.571	0.397
Sidewalk	—	—	−0.552	0.155	—	—	—	—
Collision factor								
Other angles	—	—	−1.156	0.237	−1.668	0.537	−1.325	0.736
Environmental factor								
Uncontrolled	−0.236	0.135	−0.456	0.142	0.320	0.294	—	—
Marking control	—	—	—	—	0.532	0.322	—	—
Autumn	0.367	0.155	—	—	—	—	—	—
Severe weather	1.149	0.211	—	—	0.804	1.103	—	—
<200 m	—	—	0.485	0.181	—	—	0.249	0.645
Random parameter								
Severe weather	0.804	0.212	—	—	1.149	1.853	—	—
<200 m	—	—	0.260	0.738	—	—	0.486	1.163
Heterogeneity in the means of random parameters								
Severe weather: No street lamp at nigh	—	—	—	—	0.301	0.217	—	—
Severe weather: >60	0.433	0.212	—	—	—	—	—	—
Severe weather: Uncontrolled	—	—	—	—	−0.532	1.123	—	—
<200 m: Mixed lane	—	—	−0.322	0.671	—	—	0.525	0.278
Heterogeneity in the variances of random parameters								
Severe weather: >60	1.588	0.205	—	—	—	—	—	—
Severe weather: No street lamp at nigh	—	—	—	—	1.237	0.512	—	—
<200 m: Mixed lane	—	—	—	—	—	—	1.307	1.062

Table 6: Average marginal effect result.

Variable	No violation			Existence of violation		
	NI	MI	FS	NI	MI	FS
(MI) Male	—	—	—	0.0625	−0.1177	−0.0714
(SF) Male	—	—	—	0.0347	−0.0749	−0.0841
(MI) 18–32	0.0235	−0.0643	0.0393	—	—	—
(SF) 46–60	—	—	—	0.0249	0.0724	0.0598
(MI) >60	−0.0186	0.0451	0.0693	−0.0784	0.0825	0.0928
(SF) >60	−0.0234	0.0365	0.0829	−0.0672	0.0571	0.1242
(MI) Pavement damage	0.0572	−0.0962	−0.0397	—	—	—
(SF) Pavement damage	—	—	—	−0.0166	0.0385	−0.0275
(MI) Dusk/dawn				0.0195	−0.0217	0.0336
(MI) Street lights at night	0.0133	−0.0543	−0.0337	0.0337	0.0123	−0.0315
(MI) No street lamp at night	−0.0225	0.0349	−0.0436	−0.0446	0.0391	0.0513
(SF) No street lamp at night	−0.0134	0.0293	0.0149	−0.0446	−0.0391	0.0513
(MI) Nonmotorized lane	—	—	—	0.0229	−0.0162	−0.425
(SF) Nonmotorized lane	—	—	—	0.0229	−0.4250.0162	
(MI) Mixed lane	−0.0133	0.0449	0.0266	−0.0291	0.0521	0.0531
(SF) Mixed lane	−0.0207	−0.0337	0.0316	−0.0314	−0.0473	0.0649
(SF) Sidewalk	0.2105	−0.0595	−0.0740	—	—	—
(MI) Other angles	−0.0115	0.0253	−0.0776	0.0231	−0.1104	−0.0652
(SF) Other angles	0.0217	−0.0374	−0.0813	0.0207	0.0932	−0.0851
(MI) Uncontrolled	−0.0157	−0.0519	−0.0897	0.0522	0.0442	−0.0855
(SF) Uncontrolled	0.0231	0.0474	−0.0929	0.0391	−0.0521	−0.0855
(MI) Marking control	—	—	—	−0.0137	0.0348	0.0449
(MI) Autumn	−0.0125	0.0233	0.0314			
(MI) Severe weather	−0.0395	0.0812	0.0634	0.0557	0.1204	0.0886
(SF) <200 m	−0.0127	0.0348	0.0465	−0.0216	0.0791	0.0614

parameter has variance heterogeneity with a coefficient of 0.433 when the rider's age is greater than 60 years, which will make the distribution of this random parameter wider, increase its degree of dispersion, and improve its randomness.

The mean value in the presence of violation scenario is 1.1489 and the standard deviation is 1.8527, and from the normal distribution probability density in Figure 2(b) shows that 73.24% of the electric two-wheeler riders are involved in collisions in severe weather, and the probability of sustaining minor injuries is increased. If the crash occurs in severe weather will increase the mean value of the lighting factor (no street light at night) and increase the probability of minor injuries, the presence of variance heterogeneity of this random parameter in the lighting conditions (no street light at night) with a coefficient of 0.378 will make the distribution of this random parameter wider, increasing its degree of discretization and increasing its randomness. This may be due to the fact that in severe weather, when the cyclist's field of vision is restricted and there is no lighting at night, the cyclist's presence of a violation of the law will further draw attention to the situation and lead to injuries in the event of a crash.

For visibility <200 m, the mean value in the no-violation scenario is 0.2499, standard deviation is 0.7382, and from the normal distribution probability density in Figure 3(a), it is clear that 63.31% of the e-two-wheeled vehicle riders are involved in a collision in the poor visibility condition and have an increased likelihood of severely/fatal injuries. If the crash occurs in low visibility conditions, it will reduce the mean value of the crash location factor (mixed lane) and reduce the probability of severely/fatal injuries crash, and this may be due to the fact that in low visibility conditions, the rider will be more cautious in riding in the mixed lane and hence avoiding serious crashes.

In scenarios where a violation exists, the mean is 0.4859, and the standard deviation is 1.1630. From the normal distribution probability density in Figure 3(b), it is clear that 64.06% of the e-two-vehicle riders are involved in collisions under poor visibility conditions, and the probability of severely/fatal injuries is increased. In the presence of violation scenarios, if the crash occurs in poor visibility conditions, it increases the mean value of the crash location factor (mixed lanes) and increases the probability of severely/fatal injury, and the presence of variance heterogeneity of this random parameter in the crash location factor (mixed lanes) with a coefficient of 0.459 broadens the distribution of this random parameter, increasing its dispersion and increasing its randomness.

5.3.2. Rider Factor Analysis. The rider factors were analyzed, in which the gender and age factors of two-wheeled electric vehicle riders had a significant effect on the severity of injuries in the crash, and the model results showed that:

(1) Gender of the Rider. Under existence of violation scenarios, the probability of male riders being minor injured in crash is significantly decreases by 0.1177, compared to females. Under the scenario of no violation of the law, the gender factor is not significant, and there is a certain difference between the two scenarios for this factor.

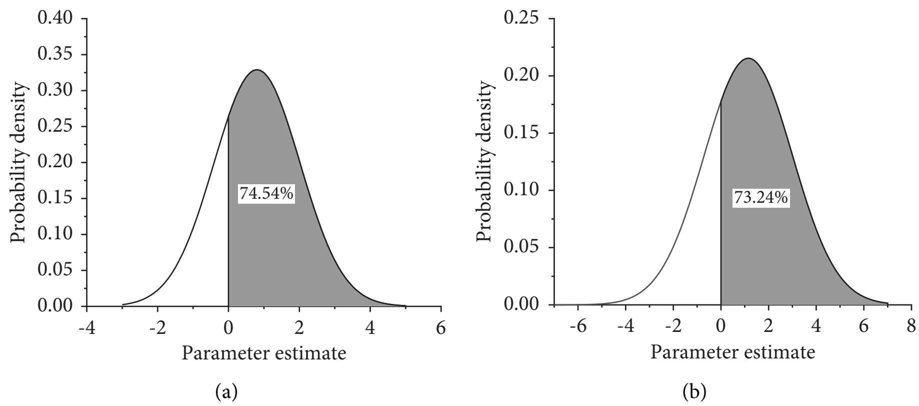


Figure 2: The distribution of severe weather random parameters in the model for injury severity analysis (a) Nonviolation. (b) Existence of violation.

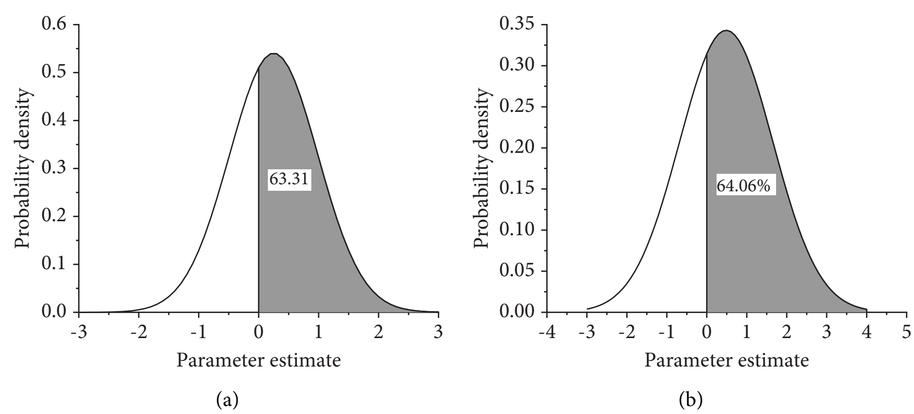


Figure 3: The distribution of visibility <200 m random parameters in the model for severely/fatal injury analysis (a) Nonviolation. (b) Existence of violation.

In scenarios where a violation exists, the probability of being injured in a collision is lower than that of females when the rider is a male, which may be analyzed due to the fact that male riders are in better physical condition and have quicker reactions compared to females and that males are better able to protect themselves with their bodily functions after a violation occurs, and therefore have a lower likelihood of being injured. Some studies have also found that an important factor in the high risk of female riding is the increase in speed [18], and speeding is among the more common violations. In the current study, the conclusion on the effect of gender on crash severity is not uniform, and some other studies hold the opposite view, that is, women are better able to avoid risks and improve their safety in the event of a crash [7].

(2) Age of the Rider. In the no violation scenario, riders in the 18–32 age range had a 0.0643 decrease in the probability of being minor injuries in a crash compared to riders <18 years old, and riders aged >60 years old had a 0.0451 increase in the probability of being minor injuries in a crash and a 0.0829 increase in the probability of being severely/fatal injury in a crash compared to riders <18 years old.

In the presence of a violation scenario, riders in the 46-60-year-old range had a 0.0598 increase in the probability of being severely/fatally injured in a crash compared to riders aged <18 years age have a 0.0598 increase in the probability of being severely/fatal injury in a crash, and those in the age >60 years of age have a 0.0825 increase in the probability of being minor injuries in a crash and a 0.1242 increase in the probability of being severely/fatal injury in a crash, compared to those <18 years of age. Young and middle-aged riders are more experienced and focused, and they can avoid dangers more effectively, but when there is a violation of the law, they are easily interfered with by the violation of the law, and their reaction speed decreases, and therefore the probability of injuries increases, and the senior riders, affected by their own physical health, healthcare, and safety, are more likely to be injured than the senior riders [19]. Elderly cyclists are not easy to take effective measures when danger occurs due to the limitations of their physical fitness, attention, and reflective ability and some of them have weak road safety awareness, which makes them more likely to violate the law when riding compared to young people. The same conclusion was reached by the study that the presence of inappropriate behavior of cyclists increases the severity of injury [5, 20, 21].

5.3.3. Road Factor Analysis. The analysis of road factors revealed that there are significant factors of road surface condition, road lighting condition, road class, and road location, which have a considerable effect on the severity of crashes involving electric two-wheelers.

(1) Road Surface Condition. Under existence of violation scenarios, the probability of riders being severely/fatally injured in crashes on pavement damage decreases by 0.0275 compared with the intact pavement good. The probability of riders being involved in crashes on pavement damage decreases in both scenarios, as the safety risk increases when riding on pavement damage. Riders pay more attention to road conditions, pay more attention, and are more cautious when riding, and are less likely to be involved in violation of the law, so the likelihood of being involved in crashes and injuries decreases.

(2) Lighting Situation. In the no violation scenario, compared to daytime, the probability of a rider being involved in an accident with minor injuries decreased by 0.0543. The likelihood of a minor injury at night without street lighting increased by 0.0349, and the probability of a serious/fatal injury at night increased by 0.0149. In the violation scenario, compared to daytime, the likelihood of a rider being involved in a minor injury crash at dusk/dawn decreased by 0.0217 and increased by 0.0123, and the probability of a rider being involved in a minor injury crash at night without street lighting decreased by 0.0217. The likelihood of a rider being involved in a minor injury collision decreased by 0.0123 during the nighttime with street lighting, and the likelihood of a rider being involved in a minor injury collision increased by 0.0391 during the night without street lighting. As can be seen from the results of the marginal effect, the factor night with street lighting in the two scenarios shows a significant difference between the two scenarios. In the presence of violation behavior scenarios, the night with street lighting and night without street lighting factors are significant, the probability of riders in crashes with minor injuries is increased, and the probability of the nighttime without street lighting situation increases more. The factor in the presence of violation behavior scenarios on the probability of minor injuries also shows an increase in the case of the lack of roadway illumination; the riders are sometimes unable to detect conflicting vehicles in time, which is more likely to result in injury crashes, and this likelihood increases further if the rider is in the presence of a violation. Previous studies also found that the probability of injury to riders is higher in the dark without lighting, and reduced visibility in the dark may lead to an extension of emergency response time for drivers and passengers [4].

(3) Location of the Crash. In the no violation scenario, the electric two-wheeled vehicle crashes occurred in the nonmotorized lane compared with the motor vehicle lane, the probability of riders being injured in crashes increased significantly, the likelihood of riders being injured in crashes increased by 0.0449, the possibility of riders being injured in crashes increased by 0.0316, and the crashes occurred in the sidewalk compared with the motor vehicle lane, the probability of riders being injured in crashes decreased significantly, the probability of severe/fatal injuries decreases by 0.0740. In the presence of violation scenarios, electric two-wheeled vehicle crashes occurring in nonmotorized lanes compared to motorized lanes, the probability of riders being injured in crashes decreases significantly, the likelihood of riders being injured in crashes decreases by 0.0162, the probability of being severe/fatal injuries decreases by 0.0425, which is a significant difference from the absence of violation scenario, and crashes occurring in the nonmotorized lanes are significantly different. The mixed motorized lanes crashes were substantially more likely to suffer minor injuries (0.0521) and severe/fatal injuries (0.0649), and crashes occurring on the sidewalk were not significant in this scenario, so there was some difference in this factor between the two scenarios.

The analysis of the road location where the crash occurred found that the probability of riders being injured in a crash increased when it happened in a mixed motorized/nonmotorized road under the scenario of no violation because the mixed motorized/nonmotorized road, with its complex road conditions, has a greater likelihood of injuries to the rider of the motorized two-wheeler in the event of a conflict between the motorized two-wheeler and the motorized vehicle. When the crash occurred in the pedestrian walkway, the two parties to the conflict were mainly motorized two-wheelers and bicycles, which are all road-vulnerable groups. After the competition, the possibility of injury to the rider is reduced; in the presence of illegal behavior scenarios occurring in the nonmotorized roadway, the possibility of minor injuries to the rider is reduced, compared to the motor vehicle roadway, electric two-wheeled vehicles in the nonmotorized lane driving in the event of a crash when the object of the conflict is mainly for the vulnerable groups of the roadway such as electric two-wheeled vehicles, bicycles, generally slower speeds, the possibility of injuries in the event of a crash is lower, in some study also found that riders who crashed on multi-use paths, sidewalks, and local streets tended to suffer more severe injuries [22, 23].

(4) Control Mode. In the no violation scenario, the probability of riders being injured in a crash at uncontrolled intersections compared to signalized intersections decreases significantly, with the likelihood of riders being injured in a crash with minor injuries decreasing by 0.0595, and the likelihood of riders being injured in a crash with severely/fatal injuries decreasing by 0.0929, respectively. The probability of riders being injured in crashes with minor injuries increased by 0.0442. The probability of riders being injured in crashes with minor injuries at signaled intersections increased by 0.0348, and this variable differed somewhat between the two scenarios. When the roadway intersection is an uncontrolled intersection, the probability of riders being injured in a crash decreases in the no-violation scenario, and

in a previous study it was found that drivers are more likely to be injured in crashes at passively controlled intersections [24], and in the presence of violation scenarios, there is a significant increase in the number of injuries sustained by riders in crashes, and the reason for the significant difference in this factor may be that at signalized intersections with the presence of a greater number of control facilities, violation behavior is generally less, so there is a certain degree of randomness, in addition, in the uncontrolled intersection, vehicle driving needs to observe the road situation, in time to reflect on the incoming traffic in the other direction, and the uncontrolled intersection is generally less traffic flow, so in the absence of violation behavior scenarios, the rider's attention is focused on the road, it is not easy to have crashes, and the possibility of having a crash with injuries decreases when the rider exists violation behaviors (e.g., speeding, answering the phone, going against the traffic), the attention is distracted, and if the car coming from the other direction, it is easy to cause a conflict, resulting in injury crashes.

5.3.4. Analysis of Collision Factors. The collision factors of electric two-wheeler vehicle crashes were analyzed, and it was found that among them, other angle collisions showed a significant effect on the severity of electric two-wheeler crashes in the scenario of no violation. Compared to side impacts, the likelihood of a rider being involved in a crash is significantly lower for other angle collisions, with the likelihood of severe/fatal injuries decreasing by 0.0813. In scenarios where there is a violation of the regulations, the likelihood of a rider being involved in a crash is significantly lower for other angle collisions. Compared to side impact crashes, the likelihood of a rider being involved in a crash decreases significantly when other angle crashes occur, the likelihood of a rider being involved in a crash with minor injuries decreases by 0.1104, and the likelihood of being involved in a crash with severely/fatal injuries decreases by 0.0851.

In summary, in the two scenarios, the probability of a crash with serious injuries or death is decreased. In the no violation scenario, riders in other-angle collision crashes suffered minor injuries, and the probability decreased in the two scenarios of other-angle collisions impacting the severity of the crash. The difference between the two scenarios is relatively small, which may be due to the occurrence of other angle collision compared to the side of the collision, the rider suffered a small direct impact, and the proportion of the occurrence of a small In the two scenarios, the influence of this factor is smaller, so the probability of riders being injured in crashes is reduced in both scenarios, and in the study on the angle of collision, it was also found that the driving route of electric two-way vehicles is more unstable, which makes it easy to have side crashes, and the side collision is the most common collision mode [25–27].

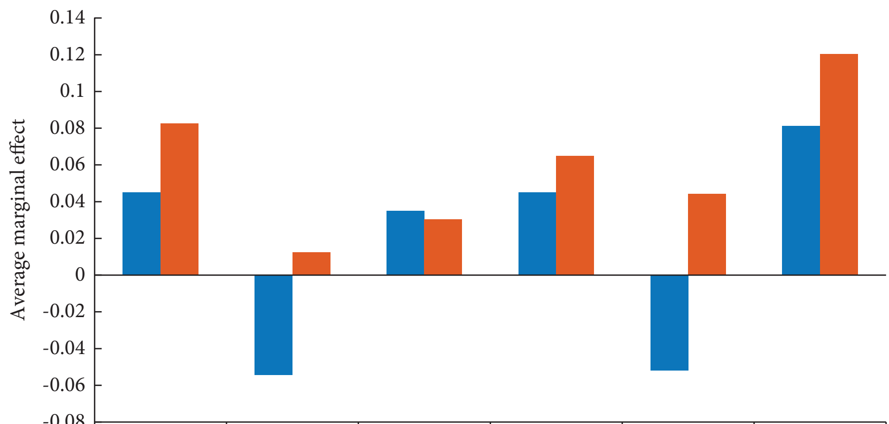
5.3.5. Analysis of Environmental Factors. An analysis of environmental factors reveals that there is a significant effect of season, weather, and visibility on the severity of electric two-wheeler crashes.

(1) Seasonal Factors. In the no-violation scenario, the probability of riders being involved in minor injuries increased significantly in the fall compared to the spring, with the likelihood of minor injuries increasing by 0.0233. In the presence of violation scenario, the seasonal factor was not significant, suggesting that there is some variability in this factor between the two scenarios. The reason for the increase in the probability of minor injuries of riders' crashes in the fall may be that the fall is influenced by the season, without the cold of winter and the heat of summer, the frequency of e-bike trips is higher, and the likelihood of crashes is also relatively higher in, this result is consistent with Zhang et al. who found that bicycle and e-bike related injuries mainly occur in the spring and the fall [28].

(2) Weather Factors. In the no violation scenario, compared with sunny days, under rain, snow, and other severe weather, the probability of riders being injured in crashes rises significantly, and the likelihood of riders suffering minor injuries rises by 0.0812. In the presence of violation scenarios, compared with sunny days, under rain, snow, and other severe weather, the probability of riders being injured in crashes rises significantly, and the likelihood of riders suffering minor injuries rises by 0.1204. In the presence of both scenarios, the incidence of rain, snow, high wind, and other severe weather, the likelihood of riders being injured in minor crashes rose in both scenarios because electric two-wheeled vehicles are susceptible to environmental influences during riding, and in the rain and snow and other weather, it is easy to have delayed braking, wheel sliding, and insufficient vision, which leads to crashes, especially when there is a violation of the rules.

(3) Visibility. In the no violation scenario, the probability of a rider being severely/fatally injured in a crash is significantly higher in visibility <200 m compared to visibility >200 m, with an increase in likelihood of 0.0465. In the presence of a violation scenario, the probability of a rider being severely/fatally injured in a crash is significantly higher in visibility <200 m compared to visibility >200 m, with an increase in likelihood of 0.0614. In the low visibility environment, both scenarios increase the likelihood of a rider being seriously injured/fatally in a crash where the rider cannot notice the danger in time, Chang et al. 0.0614. In the low visibility environment, the likelihood of riders being involved in serious injury/fatal crashes increased in both scenarios. In low visibility environments, riders are unable to notice hazards in time. Chang et al. found that the limited visibility may be related to the increased risk of injury, which is prone to crashes [4]. As to bicycle riders, distraction will increase the collision probability by 88.92%. This situation may be explained by the fact that the presence of a violation further restricts attention and thus makes it more likely to cause injury crashes [9].

5.3.6. Comparative Analysis of Violations. Through the above analysis can be found in some factors in the two scenarios there is a particular difference, after comparing the



	>60	Street lights at night	No street lamp at night	Mixed Lane	Uncont rolled	Severe weather
No violation	0.0451	-0.0543	0.0349	0.0449	-0.0519	0.0812
Existence of violation	0.0825	0.0123	0.0304	0.0649	0.0442	0.1204

Figure 4: Comparison of average marginal effects of significant factors of minor injury crashes under the scene of violation or not.

significant factors of cyclist injury severity in the scenarios with and without violations found that: in the two scenarios on the cyclist minor injury crashes present a significant impact on the factors include age >60 years old, no street lights at night, street lights at night, no control, severe weather in the two scenarios, the likelihood of the cyclist to have minor injuries are presented as significantly higher, and the factors that contribute a significant effect on the serious injury/fatal crash of riders include age >60 years old, mixed roadway, other angles of collision, no control, and visibility <200 m. The details of the comparison of the average marginal effect values are shown in Figures 4 and 5 below.

From the figure, it can be seen that there is a significant difference between having a street light at night and no control in the two scenarios, and for the other essential variables, there is also an effect on the severity of injuries in the crash. In addition, according to the previous analysis, it can be found that the variables male, 46–60 age group, nonmotorized road, sidewalk, and sign marking control have some differences under the two scenarios.

Therefore, strengthening safe cycling publicity, road safety legal education, and control for riders' violation behaviors are essential to reduce the crash rate and improve road safety.

5.4. Implications. The study identifies significant influencing factors affecting the severity of injuries to motorized two-wheeler riders in collisions. The study observes the degree of response of each influencing factor to the severity of the accident through the average marginal effect results. Analyzes the accident based on the average marginal effect results and proposes safety countermeasures for electric two-wheeled vehicles.

According to Table 6, the independent variables for increasing the probability of minor injury accidents include: (1) no violation scenarios: severe weather (0.1204), >60 (0.0451), mixed lanes (0.0449), no street lights at night (0.0349), fall (0.0233), 18–32 (−0.0643), broken pavement (−0.0962), 18–32, street lights at night (−0.0543), no control (−0.0519) and (2) under the presence of violation scenarios: >60 (0.0825), severe weather (0.0812), signage and marking control (0.0537), mixed lanes (0.0521), no control (0.0442), nighttime with no streetlights (0.0305), nighttime with streetlights (0.0123), nonmotorized lanes (−0.0162), dusk/dawn (−0.0217), other angles (−0.1104), and male (−0.1177).

The independent variables contributing to the increased probability of serious injury crashes included: (1) no violation: >60 (0.0829), <200 m (0.0614), mixed lanes (0.0316), no street lights at night (0.0149), sidewalks (−0.0740), other angle crashes (−0.0813), and no control (−0.0929) and (2) under the presence of violation scenarios: >60 (0.1242), mixed lanes (0.0649), 46–60 (0.0598), <200 m (0.0465), broken pavement (−0.0275), nonmotorized lanes (−0.0425), male (−0.0841), and other angles (−0.0851). Identifying important factors is essential for prioritizing and allocating resources to improve the safety of electric two-wheelers.

Research has shown that senior riders tend to suffer more serious injuries in electric two-wheeled vehicle collisions. Considering that seniors are often physically fragile and may suffer from underlying diseases or other health problems, annual medical reports or training programs can be set as a mandatory requirement for seniors. In addition, seniors have less knowledge of cycling-related laws and regulations and are prone to violation of rules and regulations in cycling, thus Strengthening road safety legal literacy for the elderly in order to increase the awareness of safe cycling among senior riders.

Poor lighting conditions are also crucial in serious crashes involving electric two-wheeled vehicles. In order to improve the traffic safety of electric two-wheelers at night, lighting facilities should be appropriately installed at key

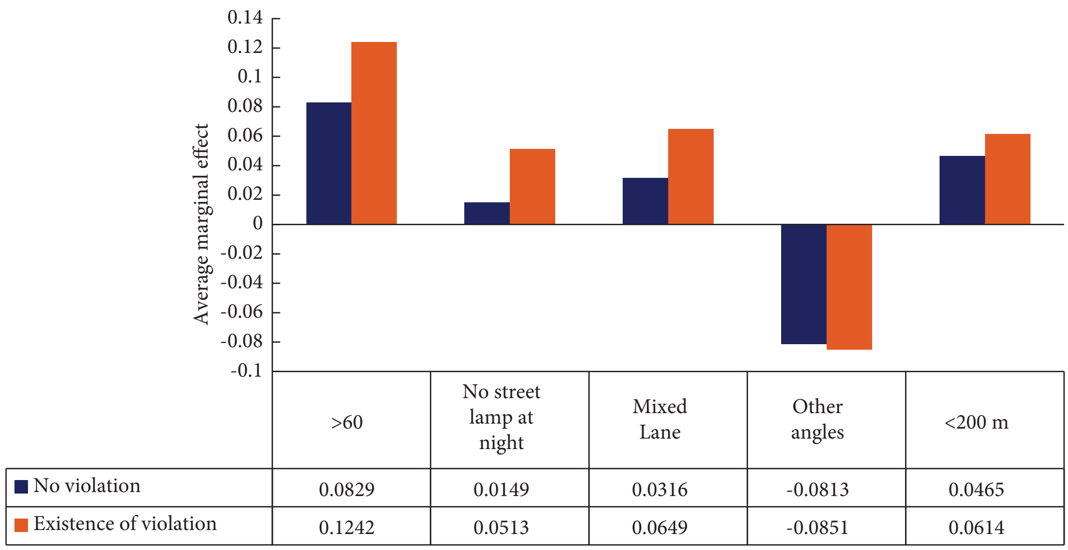


Figure 5: Comparison of the average marginal effect of significant factors of severely/fatal injuries crashes under the scene of violation or not.

road sections to enhance the visibility of road users. In addition, riders can be encouraged to wear clothing with a reflective effect through publicity and education to be more easily detected at night.

Separation design can be considered for road sections where conditions permit, so that motorized vehicles, nonmotorized vehicles and pedestrians can be separated to reduce the probability of collision between the electric two-wheeler vehicles.

In addition, according to the study of significant factors with or without violation can also be found, electric two-wheeled vehicle rider pedestrians have violation behavior, there is a considerable impact on the safety of riding, on most of the factors of the severity of the crash presents a certain degree of influence, such as >60, mixed lanes and other factors. Up to now, for the safe riding of electric two-wheeled vehicles has been introduced relevant management regulations, but in the practical application of electric two-wheeled vehicles, the supervision of electric two-wheeled vehicles, as well as the effect is poor, should be further strengthened oversight, can be considered to increase the road facilities such as for the electric two-wheeled vehicle license plate monitoring and identification facilities [14].

6. Conclusion

This study takes 6512 electric two-wheeled vehicle collisions in Shandong Province from 2015 to 2021 as the research object. Considering the unobserved heterogeneity of injury severity in electric two-wheeled vehicle collisions, a random parameter logit model (RP-HMV logit) that takes into account the heterogeneity of mean and variance was used in this study. The presence of illegal behaviors of electric two-wheeled vehicle riders was categorized and modeled. Based on the modeling results, the influencing factors of injury severity and the differences in injury severity in electric two-wheeled vehicle collisions are analyzed.

Through empirical analysis, this paper estimates three groups of models, including standard polynomial logit model, random parametric logit model, and random parametric logit model considering mean and variance heterogeneity. Also, the superiority of the random parametric logit model considering mean and variance heterogeneity is verified by AIC, BIC, and McFadden Pseudo R^2.

The model results reveal the influencing factors affecting the crash severity of electric two-wheeler riders and the effect of the presence or absence of violation behavior of the rider on the causation of crash severity. Factors that increase the severity of rider injuries in the no violation scenario include age >60, no street light at night, mixed lane, no control, fall, severe weather, visibility <200 m. Factors that increase the severity of rider injuries in the presence of violation scenarios include male, age 46–60, age >60, broken pavement, street light at night, no street light at night, mixed lane, no control, signs, and no control. Mixed lane, no controls, marking controls, severe weather, and visibility <200 m. Factors that increased the severity of cyclist injuries in both scenarios included age >60, no street lights at night, mixed lane with motorized/nonmotorized, no controls, severe weather, and visibility <200 m. Factors that differed significantly between the two scenarios were street lights at night (minor injuries) and no controls (minor injuries). Based on the factors related to the severity of rider injuries, targeted measures to improve the safety of electric two-wheeled vehicle riding are proposed from the perspective of road managers.

This study also currently has many things that could be improved. Electric two-wheeled vehicle rider violations have more classification, which also exist a certain degree of heterogeneity of the impact in the analysis of this paper, which is not taken into account. In addition, the research in this paper is aimed at the electric two-wheeled vehicle rider violations of the impact on the severity of their own crashes, but as a vulnerable group, electric two-wheeled vehicles in the event of a collision crash when the object of the motorized vehicle in electric two-wheeled vehicle—motor vehicle collision, motor vehicle drivers whether there is illegal behavior on the electric two-wheeled vehicle rider's injury severity also exists a significant impact. Currently, in the study of electric two-wheeled vehicle crashes, the rider's personal factors, such as rider education, and rider occupation have more influence. The data limit this paper, did not analyze more rider factors in-depth, and will further study the above situation.

Data Availability

Traffic accident data can only be obtained and studied by academic institutions that have signed confidentiality agreements in China.

Conflicts of Interest

The authors declare that they have no conflicts of interest that could have appeared to influence the work reported in this paper.

Acknowledgments

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